SPECTRAL ANALYSIS OF EXPLOITED FISH POPULATIONS IN LAKE KORONIA (MACEDONIA, GREECE) DURING THE YEARS 1947-1983

by

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ABSTRACT. - The exploited populations of the four dominant species of fish in Lake Koronia, as well as the total production, have been studied by spectral analysis. The species *Cyprinus carpio* and *Perca fluviatilis* display regular fluctuations with a periodicity of about 3-4 years, while *Rutilus rutilus* and *Alburnus alburnus* show random fluctuations due to fishing practices. The in-phase correlation between *C. carpio* and *P. fluviatilis* was positive with a periodicity of about 3-4 years. In contrast, no in-phase correlation was observed between *P. fluviatilis* and *R. rutilus*, due to the balance between mutual predation and competition phenomena. The decrease of the total fishing production is influenced mainly by perturbation of the water balance of the lake as well as by overexploitation.

RÉSUMÉ. - On donne l'analyse spectrale des populations exploitées de quatre espèces du lac Koronia ainsi que de la pêcherie totale. Les espèces *Cyprinus carpio* et *Perca fluviatilis* ont des fluctuations régulières, d'une périodicité de 3-4 années, tandis que *Rutilus rutilus* et *Alburnus alburnus* montrent des fluctuations accidentelles, résultant de la pratique de la pêche. La corrélation en-phase entre *C. carpio* et *P. fluviatilis* est positive avec une périodicité d'à peu près 3-4 années. Au contraire, on n'a pas observé de corrélation en-phase entre *P. fluviatilis* et *R. rutilus*, à cause de l'équilibre résultant des phénomènes de prédation mutuelle et de compétition. La diminution de la production totale a été influencée principalement par la perturbation du bilan hydrologique du lac ainsi que par la surpêche.

Key words : *Cyprinus carpio, Perca fluviatilis, Rutilus rutilus, Alburnus alburnus*, Greece, Population dynamics, Spectral analysis.

Lake Koronia, at a distance of about 10 km from Thessaloniki, and its adjacent lake Volvi form a unique system; the two lakes are connected by means of a surface channel usually full of rubbish so that communication between them to becomes very difficult, if not possible. Lake Volvi flows into the sea through the river Richios (Fig. 1).

In the past, Lake Koronia was one of the most productive lakes of Macedonia. However, it seems that this system has recently been disturbed and consequently both lake production and richness of fish populations have decreased.

In two previous papers (Economidis and Voyadjis, 1981; Economidis and Sinis, 1983), the fluctuations of the fish production of lake Koronia were examined. In the present paper we perform a spectral analysis of these fluctuations in order to reveal possible stable or even hidden temporal patterns instead of random fluctuations.

Statistical analysis based on fishing effort was not possible since parameters such as the number of fishermen, the quality and quantity of fishing equipment as

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well as fishing methods have changed considerably during the examined period. The number of fishermen has decreased, oars have been progressively replaced by engines, cotton nets have been replaced by nylon ones and they have increased in quantity (Economidis and Voyadjis, 1981; unpubl. data).

MATERIALS AND METHODS

The records of the State Office of the lake were used as raw data for the present study. The fishermen are under obligation to present their daily yield to this State Office for checking, weighting and sharing taxes. Obviously, these records are for administrative use only and so they provide rough estimates of fish population sizes rather than consistant ones. In fact, commercial needs affect fishing effort and efficiency as well as fishery species classification, since species of similar commercial value are usually listed together. However, the above data show real fluctuations of the fish populations, especially of those of high commercial value, such as *Cyrpinus carpio*, *Perca fluviatilis* and, to a certain degree, *Rutilus rutilus*.

The raw data consist of a discrete time series possibly with hidden periodicities. Although direct inspection of this time series does not reveal any temporal pattern, comparisons made between sections of such a series of data may unveil similarities in their average behaviour (Huyberechts, 1975). Among equivalent techniques designed to analyse time series, the spectral types are considered as especially powerfull in the case in which comparisons between series with hidden periodicities are required (Platt and Denman, 1975 ; Stamou and Cancela da Fonseca, in press).

In order to analyse the seasonality of specific production, periodograms have been estimated directly from raw data (Jenkins, 1961) :

$$I_{(\omega p)} = \left\{ (\sum_{1}^{N} X_t \cos 2 \pi p\, t/N)^2 + (\sum_{1}^{N} X_t \sin 2 \pi p\, t/N)^2 \right\} / N\pi$$

while in order to measure the in-phase correlation between time series the co-spectrum function, that is the Fourier transform of the cross-covariance functions γ_{xy} (p) and γ_{yx} (p) has been estimated (Chatfield, 1975) :

$$C_{xy}(\omega p) = 1/\pi\, (\gamma_{xy}(0) + \sum \left\{ \gamma_{xy}(p) + \gamma_{yx}(p) \right\} \cos \omega_p$$

where X_t is the specific production recorded at time p; N is the total number of records and ω_p frequency.

The peak occuring in the spectral graphs correspond to cycles the length of which could be determined on the frequency axe. Although available tests may determine the statistical significance of the various peaks, their relative importance is related nevertheless to their magnitude (Hacker *et al.*, 1973). So, in the case of time series in which random variations predominate, the direct inpection of the peaks may provide usefull information concerning their average behaviour. In the present paper no tests have been used.

The estimation of power spectrum derived directly from raw data as well as the estimations of co-spectrum by applying the Fourier transform on cross-covariance functions are not regular (Chatfield, 1975). So these parameters were smoothed by using the technique proposed by Stamou and Cancela da Fonseca (in press).

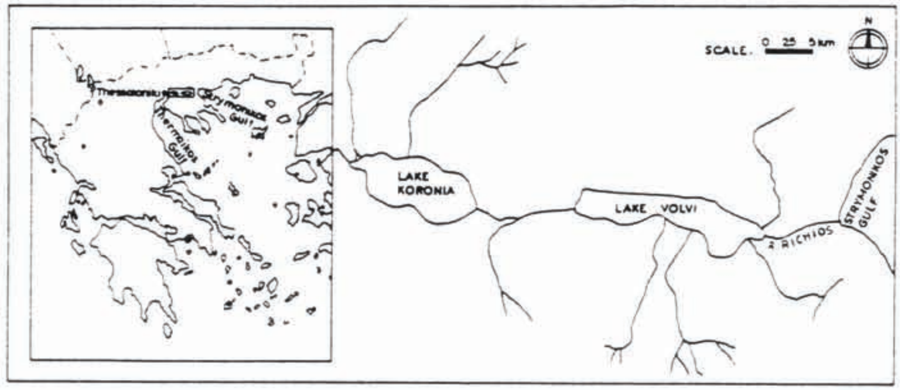


Fig. 1 : The Lake system Koronia and Volvi.

Finally, other comparisons have been made by using non parametric and parametric tests (Pollard, 1977).

RESULTS AND DISCUSSION

TOTAL PRODUCTION

Data concerning lake Koronia fish production during the period 1947-1983 are given in Table I. As it can be seen, the total production of the lake is extremely low during recent years. In general, the overall fishing period could be divided in three distinct subperiods. The first one (1947-1962) is characterized by high rates of fishing production (Table II). During this period, considerable decreases in annual fishing production have rarely been recorded, followed by an increase in production the next year so that average amounts remain high.

In 1962-63 a decrease of about 750 t was recorded, representing 68.8 % of the previous years fishing production. Notice that this percentage decrease is higher than all the previous ones. In the following eight years, instead of recovery phenomena, the observed average fishing volume remained significantly lower (Mann-Witney test) than the one recorded during the first period. Consequently this time period of eight years could be characterized as the second fishing period. The year period 1970-71 could be considered as the end of the second period, since a new considerable decrease in fishing production was observed. A striking feature in this period is that the maximum annual fishing production, 253.7 t (1971-72), is lower than the minimum, 339.6 t (1962-63), recorded during the previous time period. Average fishing volume is also statistically significant (Mann-Witney test).

In order to explain the decrease of fish production during the second period, Economidis and Voyadjis (1981) mentioned the replacement of cotton nets by nylon ones, the increase of net quantity, the modification of fishing techniques, the introduction of engines, the improvements in preservation techniques as well as transportation and commercial conditions. Undoubtedly, the above factors have had a combined, cumulative and irreversible effect on lake fishing production.

Further decrease in fishing production could be attributed to the combined effect of phenomena such as disturbance of the aquatic system, accumulation of pollutants originating from agricultural and industrial areas greatly developed during this period, as well as overfishing (Economidis and Voyadjis, 1981).

Table I. Fishing production of the lake Koronia during the period of time 1947-1983 in tons (t).

	1	2	3	4	5	6	7	8	9	10
1947-48	707.5	70.3	39.8	2.7	-	4.2	0.4	0.2	-	825.1
1948-49	261.5	242.9	198.8	7.5	-	1.8	0.7	0.6	-	713.9
1949-50	126.4	118.3	152.5	8.4	-	0.2	0.9	0.7	-	407.4
1950-51	370.6	437.0	212.1	13.6	-	0.1	0.7	1.0	-	1035.0
1951-52	158.0	725.7	214.1	44.9	-	0.1	0.7	0.6	-	1144.0
1952-53	81.3	434.7	111.6	19.0	-	2.1	0.4	0.8	-	650.0
1953-54	222.6	255.3	91.6	15.6	-	2.9	0.2	0.8	-	589.0
1954-55	855.3	284.6	23.1	15.5	-	23.4	0.2	0.6	97.6	1300.4
1955-56	132.9	114.2	8.5	6.1	-	6.1	0.2	0.4	146.2	414.6
1956-57	222.7	184.3	73.1	22.2	-	7.1	0.2	4.0	195.1	708.8
1957-58	348.2	589.0	81.8	46.1	-	0.1	0.1	1.8	58.9	1126.1
1958-59	315.0	203.8	242.1	20.2	-	0.2	0.1	2.0	256.1	1039.4
1959-60	140.8	617.1	169.4	7.4	-	+	-	2.2	487.0	1423.8
1960-61	214.1	337.1	46.7	22.4	-	+	-	1.7	41.3	663.3
1961-62	113.8	549.5	198.2	104.5	-	-	-	0.6	122.6	1089.2
1962-63	75.7	105.3	106.4	28.0	3.3	-	-	0.5	20.6	339.6
1963-64	102.5	308.0	126.3	35.7	16.4	-	-	0.7	11.0	600.4
1964-65	56.8	411.7	173.4	65.9	0.3	-	-	1.4	1.0	710.5
1965-66	14.6	407.2	86.5	44.3	0.2	-	+	2.2	0.4	555.3
1966-67	42.5	422.8	119.0	24.9	+	-	+	1.2	+	610.4
1967-68	23.9	359.0	114.5	38.6	1.0	-	-	0.2	+	537.3
1968-69	10.5	456.4	89.7	27.0	1.0	-	-	1.3	-	586.5
1969-70	28.9	249.6	107.5	49.8	6.7	-	-	0.7	-	443.4
1970-71	16.2	79.1	73.6	43.7	2.8	-	-	0.2	-	215.6
1971-72	6.6	163.5	56.2	26.9	0.2	-	-	0.4	-	253.7
1972-73	3.4	167.0	-	38.8	0.6	-	-	0.3	-	210.1
1973-74	48.4	107.5	36.1	26.3	0.4	-	-	0.1	-	218.8
1974-75	8.2	111.5	24.3	25.2	1.4	-	+	+	-	170.1
1975-76	34.8	175.9	6.0	32.8	0.3	-	-	0.1	-	249.9
1976-77	8.9	109.8	0.6	38.8	-	-	-	+	-	158.2
1977-78	37.3	65.9	-	18.5	-	-	-	+	-	121.7
1978-79	9.1	80.5	50.6	14.2	-	-	-	-	-	153.3
1979-80	18.4	56.8	113.2	18.5	-	-	-	-	-	207.0
1980-81	11.3	62.5	94.5	25.0	-	-	-	-	-	193.4
1981-82	4.9	103.4	29.5	10.1	-	-	-	-	-	148.3
1982-83	4.8	73.4	83.2	6.3	-	-	-	-	-	167.7

1, *Cyprinus carpio*; 2, *Rutilus rutilus*; 3, *Alburnus alburnus*; 4, *Perca fluviatilis*; 5, *Carassius auratus gibelio*; 6, *Esox lucius*; 7, *Silurus glanis*; 8, *Anguilla anguilla*; 9, *Abramis brama*; 10, Total; + presence.

Table II : Average volume of production.

Periods	Years (n)	$\bar{x}$	$S_{\bar{x}}$	s	range
1947-1962	15	875.3	81.1	314.0	407.4-1423.8
1963-1970	8	547.9	39.9	112.8	339.6-710.5
1971-1983	13	189.8	11.2	40.3	121.7-253.7

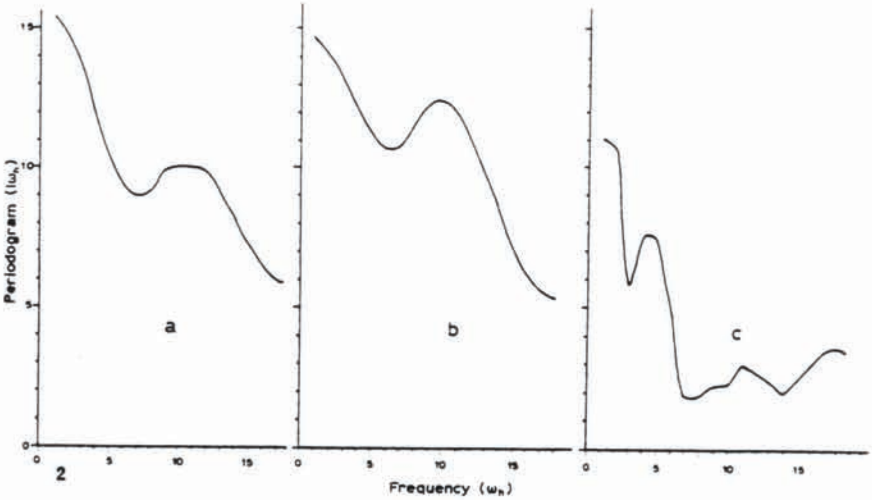
PRODUCTION PER SPECIES

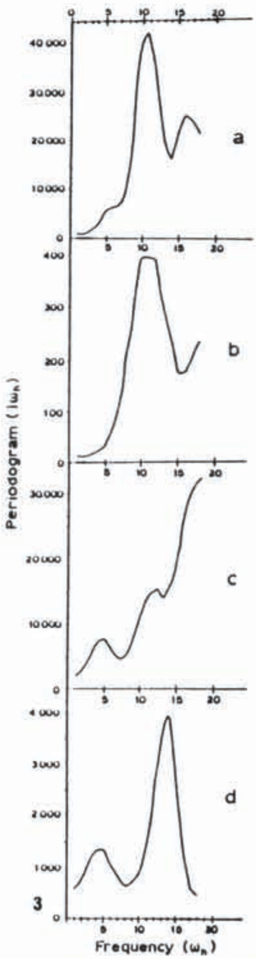
In Table I the production of nine species has also been listed, from which only four, vis. *Cyprinus carpio*, *Perca fluviatilis*, *Rutilus rutilus* and *Alburnus alburnus* appear during the whole time period in consideration (1947-1983). From the remaining species only *Anguilla anguilla* had a permanent appearance for a long time interval (1947-1978), although its production was always low. *Silurus glanis* and *Esox lucius* were present regularly in the lake during the first period 1947-1962 but their production was always low. Probably these two latter populations did not prosper in the lake Koronia when the communication with the adjacent lake Volvi, from which these species migrated, became difficult. Besides, it is known that the species *Carassius auratus gibelio* and *Abramis brama* were introduced into lake Koronia by fishermen (information obtained by fishermen and State Office), where they prospered (especially the latter) for a few years. After that, these populations decreased rapidly and finally disappeared under the environmental stress and/or because of competition with other species (Economidis and Voyadjis, 1981).

The production of *C. carpio* during the first subperiod (1947-1962) was greater than 100 t - notice the exception of the year 1952-53 - while afterwards it was low and only a few times exceeded 50 t.

In Figure 2a the smoothed periodogram estimated for the production of *C. carpio* is shown. The graph displays a peak at the frequency $\omega_p = 1$, which reflects the basic decreasing tendency of the fishing population size, which is the most revelant feature of its dynamics. This decreasing trend of population size has been removed from the raw data by using the method of presmoothing. The new periodogram (Fig. 3a) displays a peak at a frequency $\omega_p = 10$ which corresponds to a periodicity of about 3-4 years. So, besides the predominating temporal tred -possibly due to disturbance phenomena- the dynamics of the production of *C. carpio* display a secondary stable temporal pattern repeated every 3-4 years, which possibly reflects intraspecific density - dependant phenomena.

Perca fluviatilis is the main predator species of the ecosystem and after the disappearence of the species *Esox lucius* and *Silurus glanis* and the reduction of *Anguilla anguilla*, the only one. The annual average production of this species is almost doubled during the second subperiod after the disappearence of the other predator species. The periodogram estimated for the production of *P. fluviatilis* (Fig. 2b) has an analogous shape to the one estimated for *C. carpio*. The periodogram displays an inferior peak reflecting a periodicity of about 3-4 years as in the case of *C. carpio*. The peak at $\omega_p = 1$ reflects the basic tendency of *P. fluviatilis* production, that is greater yields almost in the middle of the whole fishing period and lower yields at the begining and the end of this period (Table I). This behaviour of *P. fluviatilis* production could be conceived as partially exogenous, perhaps attributable to the cotton net replacement by nylon ones in 1960-61 (Economidis and Voyadjis, 1981). The nylon nets being more resistant and efficient resulted in an increase of *P.*





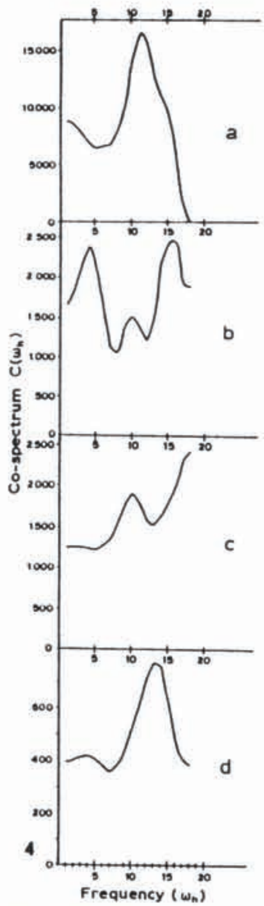


Fig. 2 : Diagrams of the periodogram : a) *C. carpio*, b) *P. fluviatilis*, c) *R. rutilus*.

Fig. 3 : Diagrams of the periodogram after prosmoothing : a) *C. carpio*, b) *P. fluviatilis*, c) *R. rutilus*, d) *A. alburnus*.

Fig. 4 : Diagrams of the Co-spectrum : a) *C. carpio* and *P. fluviatilis*, b) *R. rutilus* and *A. alburnus*, c) *R. rutilus* and *P. fluviatilis*, d) *A. alburnus* and *P. fluviatilis*.

tendency of the whole lake fish production. The periodogram for *P. fluviatilis* production estimated after raw data presmoothing can be explained in a similar way to that of *C. carpio* (Fig. 3b).

In general, the production of *R. rutilus* is the highest among the other species during the two first subperiods; until 1967-70 the production of this species has fallen below 200 t only a few times. However, in the third subperiod the production of this species decreased rapidly. The periodogram estimated for the production of *R. rutilus* reveals a periodicity of about 7-9 years - the inferior peak at $\omega_p = 4$ (Fig. 2c). The pe-riodogram estimated after raw data prefiltering (Fig. 3c) displays a shape analogous to that produced by random time series (Chatfield, 1975). Nevertheless, the peaks $\omega_p = 4$ and $\omega_p = 14$ reveal weak periodicity of about three and seven years respectively.

The production of *A. alburnus* appears with wide and random fluctuations during the whole fishing period in consideration (Fig. 3d). Although the smooth peaks reveal periodicities of about 3-4 and 7-9 years, the periodogram estimated for the production of *A. alburnus* is almost flat, reflecting random fluctuations and so it was not presented here. To this end it must be noticed that the periodograms estimated for the production of *R. rutilus* as well as for the productions of *A. alburnus* do not reveal clear temporal patterns due to the severe and random fluctuations of production.

RELATIONSHIPS AMONG SPECIES

As shown in Table III, the production of *C. carpio*, is negatively correlated to that of *P. fluviatilis* and *R. rutilus* while it is positively correlated to the production of *A. alburnus*. The yield of *P. fluviatilis* is not significantly correlated to that of *R. rutilus* while it is positively correlated to the fishing production of *A. alburnus*. The relationship of *A. alburnus* production to that of the other populations seems to be rather casual due to the wide fluctuations of the production of this species (dependent on its low commercial value which in turns results in a fishing effort influenced by the random demands of the market). Thus the population of *A. alburnus* could be considered as a stock which is never regularly fished.

As far as species relationships on the frequency domain are considered, co-spectrum graphs provide usefull information (Fig. 4). So, *C. carpio* and *P. fluviatilis* fishing production display in-phase correlation with periodicity of about 3-4 years while weak in-phase correlation with periodicity of about 7-9 years is displayed by the fishing production of *R. rutilus* and *A. alburnus*.

It seems that there is a synchronization in the production of *C. carpio* with that of *P. fluviatilis*. Possibly these two populations form a predator-prey system which remains stable during the time and seems to be inaffected by disturbance phenomena.

Table III : Coefficients of the linear correlation.

	2	3	4
1	- 0.70	- 0.99	0.72
2	-	- 0.05	0.68
3	-	-	0.89

1, *C. carpio* ; 2, *P. fluviatilis* ; 3, *R. rutilus* ; 4, *A. alburnus*.

The negative correlation between the fishing production of *C. carpio* and that of *R. rutilus* could be mainly ascribed to selective fishing. In addition, the relationship between these two species should have been influenced by the reduction of the lake surface which happened during the period 1969-70 (Economidis and Voyadjis, 1981) resulting in destruction of the coastal vegetation. According to these authors, during this third period the shore line always remained below the level it was during the second one. Furthermore the shore line did not remain at a stable equilibrium level, because of lake aquatic budget disturbance. These disturbances became more pronounced quite recently, since from April to September the lake as well as subterranean waters have been used for arable irrigation. Consequently the lake became more shallow and so more liable to temperature changes, turbidity, water circulation, etc. These facts should have influenced all fish species, but mainly the reproduction of *C. carpio*, which prefers to lay eggs on young coastal plants (Balon, 1975). A similar phenomenon was observed in the same lake during the years 1930-34 (Athanassopoulos, 1935). The co-spectrum graph (Fig. 4a) shows a significant in-phase correlation between the fishing production of *C. carpio* and *P. fluviatilis* at high frequencies, a fact possibly relating to the above mentioned phenomena.

No correlation between fishing production of *P. fluviatilis* and *R. rutilus* has been recorded. It is difficult to explain this fact since there is expected to be a predator-prey relationship between these two species. Nevertheless, it is known that predatory behaviour is displayed mainly by *P. fluviatilis* mature females, while *R. rutilus* feeds on eggs of other species including *P. fluviatilis* (Holcik, 1977 and personal observations). Besides, the canibalism of *P. fluviatilis* (Nikolsky, 1963 ; Holcik, 1977 ; etc.) results in a decreasing predation efficiency of this population on other ones. Thus according to the above statements the neutral relationship of fishing production of *P. fluviatilis* to that of *R. rutilus* could be interpreted as follows : the predation efficiency of *P. fluviatilis* on *R. rutilus* is balanced by the predation efficiency of *R. rutilus* on the eggs of *P. fluviatilis* as well as by the canibalism exercised among the individuals of *P. fluviatilis*.

GENERAL CONCLUSIONS

1. The total fishing production of lake Koronia decreased during the last years. This seems to be influenced by two factors :

- The reduction of the lake surface - due to the increased needs for irrigation - which results in destruction of the costal vegetation, the preferential site for reproduction of many species ;
- The improvement of fishing techniques resulting in overexploitation phenomena.

2. The richness of lake Koronia is decreased partially due to the interruption of the communication of the lake with the adjacent lake Volvi.
3. The dynamics of *C. carpio* and *P. fluviatilis* display regular fluctuations with periodicity of about 3-4 years while the dynamics of *R. rutilus* and *A. alburnus* display random fluctuations.
4. The dynamics of the relationship of *C. carpio* to that of *P. fluviatilis* seem to be determined by intrinsic factors of predator-prey type.

C. carpio and *P. fluviatilis* form the only well defined predator-prey system in the lake which seems to remain unaffected by disturbance phenomena.

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